LOW VELOCITY IMPACT RESPONSE OF RC BEAM WITH ARTIFICIAL POLYETHYLENE AGGREGATE AS CONCRETE BLOCK INFILL

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A thesis submitted in
fulfillment of the requirement for the award of the
Doctor of Philosophy

Faculty of Civil and Environmental Engineering
Universiti Tun Hussein Onn Malaysia

January 2018

To my supervisor and family, thank you for your support.

ACKNOWLEDGEMENTS

All praises are due to **ALLAH** Subhanahu Wa Ta'ala for inspiring me with strength and energy to achieve this modest study. I am deeply grateful to all those who have encouraged and supported me, discussed ideas and insights, which have contributed in various ways to complete my study. I would like to thank the supervisor Dr. Shahrul Niza Mokhatar, for his support throughout the research, to the co-supervisor Dr. Zainorizuan Bin Mohd Jaini and Dr. Josef Hadipramana, to the University Tun Hussein Onn Malaysia for the financial support Geran Insentif Penyelidik Siswazah (GIPS) Vot U271 and Research Support Grant Scheme (RSGS) Vot U100.

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ABSTRACT

In structural design, an ideal situation for saving materials would be to reduce the weight of the structure without having to compromise on its strength and serviceability. A new lightweight composite reinforced concrete section was developed with a novel use of a lightweight concrete block as infill utilizing Artificial Polyethylene Aggregate (APEA and MAPEA). The concrete near the neutral axis acts as a stress transfer medium between the compression and tension zones. Partial replacement of the concrete near the neutral axis could create a reduction in weight and savings in the use of materials. In this experimental work, APEA and MAPEA were utilized as replacement for normal aggregates (NA) at percentages of 0%, 3%, 6%, and 9%, 12%, and 100% in the concrete mix. In this study, the concrete block infill uses the 100% MAPEA as a replacement for coarse aggregate. A total of sixteen beams were prepared measuring 170 mm × 250 mm × 1000 mm, in which four specimens were used as control samples (NRC) and twelve specimens were the reinforced concrete beam incorporated with different size of concrete block infill (RCAI) consisting of 100% MAPEA. All beams were tested with 100 kg steel weight dropped vertically from a height of 0.6 m and 1.54 m, which was equivalent to 3.5 m/s and 5.5 m/s respectively. Based on the experimental results, the impact force, displacement and crack patterns were affected by the impact load. For RCAI specimens, the impact force was larger but smaller displacement value was observed, compared to the NRC specimens. Furthermore, the width of the cracks generated in the RCAI specimens near the mid-span was less than that on the NRC specimen. All experiment results were validated against FEM. The transient impact force histories, displacement and crack patterns obtained from FEM matched reasonably well with the experiment results. The error reported a range of 1% to 15%. The results showed that the proposed use of concrete block infill produced desirable results under the impact loads. The main advantages of the concrete block infill that utilized MAPEA from waste plastic bags due to the weight reduction about 6% in the concrete beams.

ABSTRAK

Dalam reka bentuk struktur, keadaan ideal untuk menjimatkan bahan adalah dengan mengurangkan berat struktur tanpa perlu berkompromi pada kekuatan dan kebolehkhidmatan. Konkrit bertetulang ringan komposit yang baru telah dibangunkan dengan penggunaan blok konkrit ringan yang baru sebagai *infill* dengan menggunakan Artificial Polyethylene Aggregate (APEA dan MAPEA). Konkrit berhampiran paksi neutral bertindak sebagai medium pemindahan tekanan antara zon mampatan dan ketegangan. Penggantian separa konkrit berhampiran paksi neutral boleh mengurangkan berat dan penjimatan dalam penggunaan bahan. Dalam kajian ini, agregat tiruan yang dinamakan sebagai APEA dan MAPEA telah digunakan sebagai agregat kasar dalam campuran konkrit pada peratus 0%, 3%, 6%, and 9% %, 12%, dan 100% enam belas rasuk konkrit disediakan berukuran 170 mm × 250 mm × 1000 mm, di mana empat spesimen digunakan sebagai sampel kawalan (NRC) dan dua belas spesimen adalah rasuk konkrit yang digabungkan dengan blok konkrit *infill* (RCAI) yang mengandungi 100% MAPEA Semua rasuk konkrit diuji dengan hentaman 100 kg berat besi yang jatuh secara menegak dari ketinggian 0.6 m dan 1.54 m, bersamaan 3.5 m / s dan 5.5 m / s. Berdasarkan keputusan eksperimen, daya impak, anjakan dan corak keretakan dipengaruhi oleh keadaan beban impak. Bagi spesimen RCAI, daya impak adalah lebih besar dan nilai anjakan lebih kecil berbanding dengan NRC. Selain itu, lebar retak yang dijana dalam RCAI berhampiran tengah rentang kurang daripada NRC. Semua keputusan eksperimen telah disahkan melalui FEM. Beban hentaman, anjakan dan corak keretakan yang diperoleh dari FEM dipadankan dengan baik dengan keputusan eksperimen. Perbezaan yang dilaporkan dalam lingkungan 1% ke 15%. Ini menunjukkan bahawa penggunaan blok konkrit *infill* yang dicadangkan menghasilkan keputusan yang diingini.–Kelebihan utama blok konkrit *infill* yang mengandungi MAPEA dari beg plastik sampah ialah dapat mengurangkan berat sebanyak 6% dalam rasuk konkrit tersebut.

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LIST OF SYMBOLS

A	-	Weight in grams (g) of the oven dry sample in air
B	-	Weight in grams (g) of the Surface dry sample in air
C	-	Weight in grams (g) of the Surface dry sample in air
D:	-	Diameter of the cylinder.
L	-	Length of the cylinder.
v	-	Velocity
g	-	Gravity (9.81m/s^2)
h	-	Height
APEA	-	Artificial Polyethylene Aggregate
MAPEA	-	Modified Artificial Polyethylene Aggregate
NA	-	Normal Aggregate
AIV	-	Aggregate Impact Value
ACV	-	Aggregate Crushing Value
S.G	-	Specific gravity
ε_0	-	The concrete strain at the end of the parabolic section
w	-	The distance from the neutral axis to strain
k_2	-	Depth to the centroid of the stress block.
X_u	-	Depth of the neutral axis.
b	-	Width of beam
D	-	Total depth of the beam
d	-	Distance between mid of steel to top of beams
$d_{\max}$	-	Distance between surface beams to end of block replacement zone
$d_{\min 1}$	-	Distance between surface block replacement zone to top of beams for (RZ-1)
$d_{\min 2}$	-	Distance between surface block replacement zone to top of

		beams for (RZ-2)
$d_{\min 3}$	-	Distance between surface block replacement zone to top of beams for (RZ-3)
d'	-	Concrete layer thickness necessary to maintain the bond between concrete and steel
x_{b1}	-	Distance between surface block replacement zone to compression force for (RZ-1)
x_{b2}	-	Distance between surface block replacement zone to Compression force for (RZ-2)
f_{ck}	-	Compressive strengths of normal concrete
f_{MAPEA}	-	Compressive strengths of concrete mix containing 100% MAPEA
ASTM	-	American Standard Test Method
BS	-	British Standard
EC2	-	Euro code 2
FEM	-	Finite element method
LVDT	-	Linear Variable Differential Transformers
NRC	-	Normal reinforced concrete beam
RC	-	Reinforced concrete
RCAI (RZ)	-	Reinforced Concrete beam incorporated with differently positioned Replacement Zones concrete block infill

CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete is the most widely used man-made construction material in the world and second, only to water as the most utilized substance in the planet (Sumajouw & Rangan, 2006). One way to improve the concrete structure is to modify the concrete mixture itself. Modifying the concrete is one way of improving the concrete structure. Researchers had used numerous types of additional material to ensure that the concrete was strong and able to receive the load applied to it. Some of the materials that acted as coarse aggregate were Expanded Polystyrene (EPS), Polyethylene Terephthalate (PET) and rigid polyurethane (PUR) (Sayadi *et al.*, 2016; Tapkire & Kumavat 2014 ; Fraj *et al.*, 2010). In this study, Low-density Polyethylene (LDPE), acting as the Modified Artificial Polyethylene Aggregate (MAPEA), was the coarse aggregate in the concrete mixture aimed at improving the concrete's strength and produce a lightweight concrete. Given that sustainable consumption and production are of high priority, proper materials for concrete aggregates as well as being a form of waste disposal system are the main concerns of the construction industry at present. Recycled plastics were used to prepare coarse aggregates, which provided a sustainable option to deal with the reduction of plastic wastes. Utilization of recycled plastics as concrete aggregates poses an advantage, both for the environment and the construction industry. Furthermore, MAPEA are lighter in weight and have lower crushing values compared to stone aggregates (Raghatate, 2012).

Concrete has low tensile strength, therefore when a reinforced concrete structure is subjected to flexural, the concrete area under the neutral axis of cross-section is considered ineffective when it is in tension at the ultimate limited state. Therefore, the ineffective volume of reinforced concrete structure can be replaced by another material, in many-sided and interest, the concrete block infill or prefabricated lightweight concrete is highly likely to be used. Consequently, it produces a lighter and compositeness reinforced the concrete structure. Extensive research has been conducted on lightweight options, which include lightweight concrete (Bobrowski, 1980; Bungey & Madandoust, 1994; Ahmad *et al.*, 1994), hollow structure or prestressed hollow-core concrete slabs (Hegger *et al*., 2009; Alnuaimi *et al.*, 2008), and composite sandwich structures (Russo & Zuccarello, 2007; Abbadi *et al*., 2009; Meidell 2009) to enhance structural performance. Despite significant efforts to investigate the composite sandwich sections to minimize the weight of the structure, limited attempts have been conducted in incorporating Autoclaved Aerated Concrete (AAC) with normal reinforced concrete (RC) (Vimonsatit *et al.*, 2012).

In reinforced concrete structures, the material properties, weight and structural geometric are put into the indicator of performance and serviceability. Basically, concrete is highly designed to carry compression while steel reinforcements transfer tension stress and loading. The relationship between tension stress and strain in a normal concrete cross-section is almost linear at small values of stress. However, if the stress higher than about 40% of the compressive strength, the tension stress and strain become increasingly affected by the formation of micro-cracks at the interface between the cement and coarse aggregate (Vimonsatit *et al.*, 2012). The micro-cracks also initiate around the bonded the region of steel reinforcements and concrete. The inner part of the reinforced concrete structure under the neutral axis only acts as a passive volume that has a small contribution on the crack and failure resistance. However, the deformation of the reinforced concrete structure still largely depends on the whole volume of structure that basically can be investigated using flexural or shear capacity tests. The relation of strain and stress is useful to understand the behaviour of the reinforced concrete structure. (Jaini *et al.*, 2016)

Response of RC structures to impact is different from that caused due to static load. Also, impact load is a particular type of dynamic loading which needs special attention. There are several categories of impact loading, and specifically, these are low velocity (large mass), intermediate velocity, high/ballistic velocity (small mass), and hypervelocity impact. These categories of impact loading are important because there are extreme changes in energy transfer between the projectile and target, energy dissipation and damage propagation mechanisms as the velocity of the projectile varies (Naik & Shrirao, 2004). Low-velocity impacts occur at a velocity below 10 m/s, intermediate impacts occur between 10 m/s and 50 m/s, high velocity (ballistic) impacts have a range of velocity from 50 m/s to 1000 m/s, and hypervelocity impacts have the range of 2 km/s to 5 km/s (Vaidya, 2011). Broadly, the impact load involves collision of vehicle into crash barriers, piers of bridges, drop of an object on beam, bullet or missile hitting structures, birds hitting airplane etc. In context of Civil Engineering problem, an investigation into the impact behaviour of RC members subjected to low velocity large mass is very important. The current work deals with low velocity large mass impact on RC structures. Low velocity impacts can be defined as events which can occur in the range 1–10 m/s depending on the target stiffness, material properties and the projectile mass and stiffness (Shivakumar *et al.*,1985)

A concrete structure subjected to impact loading might deform, both internally and externally. For example, the internal effect faced by the concrete structure due to a projectile impact might result in a number of failure mechanisms such as crushing, plug formation and scabbing. The external effect usually results in a bending failure. There are a number of approaches used to investigate the effect on the concrete structure subjected to impact loading, such as experimental tests leading to empirical formulae, analytical approaches using mass-spring systems and/or vibrations and numerical techniques such as the finite element method.

1.2 Problem of statement

Low-density Polyethylene (LDPE) is a widely used material in Malaysia, where it is utilized virtually by all industries. Its production and usage are increasing rapidly because of its perceived feasibility, long life, and low cost. This increased utilization has correspondingly increased the amount of waste. In Malaysia, 0.8 kg of Polyethylene material is wasted daily. In urban areas, waste production has been estimated to 1.5 kg daily. Plastic bags waste LDPE considerably contributes to the increasing production of solid waste in Malaysia, with only 1% to 3% of such waste being subjected to recycling. (Zoorob, 2000). The disposal of plastic bags as Polyethylene, particularly by burying them, can be problematic for any societies because most of these materials are non-biodegradable. The use of plastic bags is not only a major problem in landfills, but also presents adverse effects on the environment. Thus, innovative solutions must be developed to solve this growing problem. Recycled plastic can be used as coarse aggregates in concrete. Mustafa *et al.*, (2011) and Mokhatar *et al.*, (2014) has been found that the compressive concrete containing more 10% PE aggregates are lower than normal concrete, but the optimum prestige of LDPE aggregate is suitable for coarse aggregate replacement in concrete through their physical analysis.

The direct applications of LDPE - concrete as a concrete structure are still in doubt due to its strength. However, LDPE - concrete can be used as infill for RC beam. The combination of LDPE - concrete infill and normal concrete produces so-called composite-based-concrete-structure that has an advantage due to lighter weight. According to the various literature reviews, it is observed that there is a problem related to the depth and continuity of infill block. RC beam is highly designed to carry compression while steel reinforcements transfer tension stress and loadings. The relationship between transfer tension stress and strain in normal concrete cross-section is almost linear at a small value of stress (for stresses less than 40% of the compressive concrete strength). In this condition, the inner part, near neutral axis, only acts as a passive volume that has a small contribution to the crack and failure resistance. In addition, when an RC structure is subjected to flexural and shear, the concrete volume under the neutral axis of the cross-section is considered ineffective when it is in tension at ultimate limit states (Mohamad, & Muhammad, 2011; Patel, 2013; Mokhatar *et al.*, 2014). Thus, this study aimed to present the results of the impact tests on the reinforced concrete beam (NRC) and reinforced concrete beam incorporated with concrete block infill (RCAI) consisting of MAPEA with differently positioned Replacement Zones (RZ) of concrete block infill as well as to propose a novel lightweight reinforced concrete (RC). The block infill can be placed within the beam cross-section near the calculated depth of the neutral axis. It is vital to employ the latest technology, which is the combined Finite Element Method (FEM) by ANSYS, to ensure the accuracy and credibility of the numerical results, especially when referring to composite structures behaving in a complex manner.

1.3 Objectives

The objectives of this research are as follows:

i. To characterize the material properties and strength of concrete mix with the optimum percentage of Modified Artificial Polyethylene Aggregate (APEA and MAPEA).
ii. To determine the replacement zone of concrete block infill with MAPEA for RC beam
iii. To predict the impact response of RC beam with Modified Artificial Polyethylene Aggregate (MAPEA) block infill under low-velocity impact loads using proposed empirical formula.
iv. To simulate the impact failure of RC beam incorporated with concrete block infill consisting of MAPEA

1.4 Scope of research

The scope of this study is described as follows:

1. This study focused on two different types of Artificial Polyethylene Aggregate (APEA and MAPEA) as replacements for normal aggregate (NA). A Recyclable Artificial Polyethylene Aggregate measuring 30 mm was gathered and then heated in an oven at approximately 150 °C for nearly 10 min.
2. To investigate the physical properties of APEA and MAPEA and NA, such as aggregate impact value, aggregate crushing value, specific gravity, and water absorption.
3. To study the mechanical properties, such as compressive strength Young's modulus, Poisson's ratio and tensile strength of concrete mixed with different types of aggregates NA, APEA and MAPEA and different percentage about 3%, 6%, 9%, 12% and 100%.
4. The experimental work involved the casting of sixteen beams of 170 mm × 250 mm ×1000 mm in which, four specimens were used as control samples (NRC) and twelve specimens were used as the reinforced concrete beam incorporated with concrete block infill (RCAI) consisting of 100% MAPEA with differently

positioned Replacement Zones (RZ) block infill RCAI (RZ-1), RCAI (RZ-2) and RCAI (RZ-3).

5. The reinforced concrete beam (RC) with artificial aggregate concrete block replacement zone infill RCAI (RZ-1, RZ-2, RZ-3) designs were based on Eurocode 2 as following :
   i. The RCAI (RZ-1) beams contained 100 % MAPEA with 50 mm width, 115 mm height and 1000 mm length, and were provided for the block infill.
   ii. The RCAI (RZ-2), beams with different block infill positions, contained 100 % MAPEA with 50 mm width, 95 mm height and 1000 mm length.
   iii. The RCAI (RZ-3), beams were containing five standard cubes with 100 mm width, 100 mm height and 100 mm length.
6. The impact behaviour of the NRC and RCAI (RZ-1,2,3) were determined by a drop 100 kg steel weight attached to the load cell that was dropped vertically from a height of 0.6 m and 1.54 m, which was equivalent to 3.5 m/s and 5.5 m/s, respectively.
7. The finite element method (FEM) in ANSYS was also used to validate the experimental results.

1.5 Significant of Study

One of the advantages that can be drawn from this study is the solution for the disposal of a large amount of plastic materials by recycling and reusing plastic materials in the concrete industry, which is considered the most feasible application. Recycled plastic can be used as coarse aggregate in concrete. Aggregate production from plastic can produce lightweight concrete characteristics. The main requirement for this type of lightweight concrete is that it should exhibit adequate strength and low density to avoid cracking. This study aims to investigate the change in the mechanical properties of concrete with the addition of modified plastic as a coarse aggregate replacement in concrete and to evaluate the strength of the concrete structure of the concrete block infill. The results of the samples and laboratory tests can be used as references for future works. Furthermore, the development of analysis using FEM through the implementation of the appropriate constitutive model, which can effectively simulate the effect of the failure of the RC beam with MAPEA, can be proposed.

1.6 Structure of thesis

This thesis consists of 7 chapters:

i. The first chapter identifies the aims and scope of this research.
ii. Chapter 2 describes previous research work related to plastic as coarse aggregate, lightweight concrete, hollow structure, composite, sandwich concrete, RC beam under impact load and utilizing ANSYS to simulate the reinforced concrete behaviour.
iii. Chapter 3 describes the experimental work. Materials and equipment used in the test program, the specimen details and the test procedure used are reported here. The presentation and analysis of experimental test are given in chapter 4 and chapter 5.
iv. Chapter 6 explains the Finite Element analysis used in this study. In this chapter, test results from the experimental work are compared with the Finite Element Analysis.
v. Chapter 7 summarizes the findings of this investigation and presents a set of conclusions. Recommendations for further work are also given in this chapter.

1.7 Novelties

i. To innovate Modified Artificial Polyethylene Aggregate (MAPEA): This exploratory aspires to have an alternative source of replacing natural aggregate with plastic wastes. An investigation of the MAPEA) as natural aggregate replacement in concrete through an experimental work was conducted in this study.
ii. To determine the appropriate location of concrete block infill replacement zones: This thesis presents the novel design of RC beam with (MAPEA) concrete block infill. The combination of (MAPEA) concrete block infill and normal concrete beam produces composite-based concrete-structure that has an advantage due to the lighter weight.

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